Potential Impacts of Hypoxia on Fisheries: Louisiana's Fishery-Independent Data

James G. Hanifen, William S. Perret, Ralph P. Allemand, and Terry L. Romaire
Louisiana Department of Wildlife and Fisheries
Marine Fisheries Division
P.O. Box 98000
Baton Rouge, LA 70898-9000

Abstract

The harvest of marine fishery resources of Louisiana, valued at over one-half billion dollars annually and dependent upon the State's nutrient-rich estuaries, potentially are subject to impact from hypoxia. Hypoxic conditions periodically develop in near shore waters in many areas of the world, including the northern Gulf of Mexico. Salinity and temperature stratification in the nearshore Gulf of Mexico results in conditions conducive to the development of hypoxic and anoxic bottom waters west of the Mississippi River delta. Stable summer weather patterns, freshwater inflow from the Mississippi River and local precipitation, and nutrient enrichment from these sources contribute to increased bacterial decomposition and oxygen demand in near-bottom waters. The magnitude of the phenomenon, in terms of depression of dissolved oxygen concentration and areal extent along the coast, varies annually. Likewise, impacts to fisheries vary. The distribution of fishery species is affected by displacement of demersal nekton and mobile epibenthic species assemblages and communities to areas with sufficient dissolved oxygen, and disruption of species movement patterns. Planktonic stages of fishery species are subject to stress and mortality in hypoxic waters. Preliminary indications are that pelagic species have not been impacted, although severe hypoxic conditions extending high into the water column may have affected their distribution and move ment patterns. Other potential impacts to Louisiana's fisheries include: concentration of fishing effort resulting in increased harvest; localized overfishing in some areas; shellfish mortality if hypoxic conditions impinge on coastal bay waters, localized mortality of finfish and shellfish in shoreline areas; and decreased recruitment due to impacts to zooplankton species assemblages. Changes in the relative amounts of nutrients can affect phytoplankton community dynamics, resulting in changes throughout the food web; replacement of diatoms with dinoflagellates may result in development of red and brown tides with resultant adverse impacts to fisheries. Changes in the distribution and abundance of fish species will result in a loss of commercial and recreational harvest opportunities and a net economic loss to the State. Economically marginal commercial participants may leave the fishery, and some recreational participants may elect not to fish. Fishery management decisions that are based on fishery independent data from resource surveys that do not take hypoxia into account may result in a loss of precision in assessment of fishery stocks.

Introduction

The harvest of the commercial and recreational marine fishery resources of Louisiana is valued at over one-half billion dollars annually, and generates over 1.2 billion dollars in economic activity in the state of Louisiana (David LaVergne, Economist, Louisiana Department of Wildlife and Fisheries (LDWF), personal communication). These fisheries, the products of which are used nationally and internationally, are dependent upon the State's nutrient-rich estuaries and nearshore waters of the Gulf of Mexico. They potentially are subject to impacts resulting from the occurrence of hypoxic dissolved oxygen (D.O.) concentrations of less than 2.0 mg/l) conditions in the bottom waters of the nearshore Gulf of Mexico. This phenomenon off Louisiana represents a potential threat to the health and viability of these fisheries.

Hypoxic bottom waters offshore from the Louisiana coast were reported initially from 1935 (Richards, 1957; Conseil Permanent International pour l'Exploration de la Mer, 1936; cited in Bedinger, et al., 1980), and subsequently have been studied and reported by numerous investigators (Ragan, et al., 1978; Harris, et al., 1978; Bedinger, et al. 1980; Harper, et al., 1981; Stuntz, et al., 1982; Turner and Allen, 1982a; 1982b; Rabalais, et al., 1985; Renaud, 1986; Rabalais, et al, 1994; Schurtz and St. Pe', 1984). The Mississippi River flood that ultimately resulted in an unprecedented area of hypoxic water bottoms during the summer of 1993 focused national attention on the Louisiana coast (e.g., Holstrom, 1993).

LDWF has collected hypoxia-related data through its Coastal Study Area fishery management program since its inception in 1966. Other study-specific programs, such as the Cooperative Gulf of Mexico Inventory (Barrett, et al., 1971; Perret, et al., 1971) also have contributed to the Department's understanding of the relationships between environmental factors and coastal fisheries.

LDWF noted the occurrence of hypoxic conditions in 1973 and began regular monitoring of Gulf waters in which hypoxic conditions occur in 1978 (Foote, 1982). In 1982, funding became available from the National Marine Fisheries Service (NMFS) for the Southeast Area Monitoring and Assessment Program (SEAMAP), and limited additional data were collected by LDWF from across the central coast. The expansion of SEAMAP in 1985 provided the opportunity to collect data related to hypoxia and its potential impacts to fisheries from water depths of 5 to 20 fathoms between the Mississippi River and Atchafalaya Bay (Figure 53). The data presented here were collected primarily for other fishery management and environmental monitoring purposes, not specifically for measuring the impacts of hypoxia on fisheries. All fisheries-related data were collected using otter trawls of various sizes and configurations, and the findings are presented as a descriptive summary. Datasets have been combined to illustrate the potential impacts of hypoxia and have not been subjected to rigorous statistical analysis.

Physical and Chemical Data

Hypoxic conditions periodically develop in near-shore waters in many areas of the world, including the northern Gulf of Mexico. (Richards, 1957; Faganeli, et al., 1983). Factors hypothesized to contribute include organic sediment loads (Richards, 1957; Ragan et al., 1978), reduced vertical mixing of the water column due to salinity and temperature stratification coupled with benthic and planktonic respiration (Turner and Allen, 1982a; 1 982b). Stable summer weather patterns, freshwater inflow from the Mississippi River and local precipitation, and nutrient enrichment from these sources contribute to increased bacterial decomposition and oxygen demand in near-bottom waters (Richards, 1957; Turner and Allen, 1982a; 1982b). Salinity and temperature stratification in the nearshore Gulf of Mexico results in conditions conducive to the development of hypoxic and anoxic bottom waters west of the Mississippi River Delta (Figure 54). Typically, only the near-bottom waters become hypoxic/anoxic, principally during the months of May through August (Figure 55). The phenomenon develops because of stable local summer weather patterns that do not provide sufficient energy in terms of wind and wave action to break the density barriers established between the upper and lower water column. The barriers thus established by salinity and temperature isolate the lower reaches of the water column where oxygen demand from respiration and decomposition deplete dissolved oxygen. The resulting hypoxic/anoxic condition persists until the water column again is mixed by a frontal passage, tropical weather system, or other disturbance. Once the disturbance has passed and stable conditions again prevail, hypoxia generally becomes re-established. The regular passage of cold fronts beginning in the fall causes the water column to mix and remain in that state until the next summer.

The magnitude of the event varies annually in terms of the size of the hypoxic area and the depression of D.O. concentrations. This is illustrated by the frequency of encountering a location with hypoxic bottom water. The Midwestern drought in the late 1980's resulted in a relatively small number of nearshore hypoxic observations. Conversely, during the Mississippi River flood of 1993, a record number of hypoxic stations were encountered during routine sampling (Figure 56). The severity of the depression of D.O. levels also indicates the variability of the event. Hypoxic conditions might develop over a large geographical area, but the depression in D.O. levels might be slight as compared to other years. For example, LDWF data indicate that the 1984 event was moderately severe with over 10 percent of samples containing D.O. concentrations of less than 2.0 mg/l, or approximately half the number of stations found in the record event of 1993. However the mean D.O. concentration from samples collected during the summer of 1984 was greater than 3.0 mg/l (Figure 57), indicating that the hypoxic event that year was of shorter duration or covered a smaller area than in other years. During 1993 over 20 percent of stations sampled were found to be hypoxic, and D.O. concentrations were near 0.0 mg/l, indicating a large, severe event.

Concentrations of silicates in surface waters during spring months, although not attributable to hypoxia, show a relationship with its subsequent development. Silicates comprise the skeleton of diatoms, the dominant phytoplankton group in the northern Gulf of Mexico. High concentrations of silicates generally are followed by low measurements of D.O., and vice versa (Figure 58). High levels of silicates in the spring may indicate the potential for a subsequent bloom of diatoms. As these complete their lifecycle and settle into the bottom waters, decomposition consumes the available D.O. and contributes to the hypoxic event. Nutrients remaining in the surface waters are then available to other phytoplankton groups such as cyanobacteria and dinoflagellates. These organisms have been linked to formation of hypoxic bottom waters (Dortch, 1994). Shifts in the species composition of this community may make conditions favorable for blooms of the noxious and toxic phytoplankton that cause red tides.

Impacts to Fisheries

The presence of hypoxic waters in an area can be expected to have a variety of impacts to fisheries. Nekton communities and assemblages, being mobile, will move away from areas with insufficient D.O. and congregate along the borders of the hypoxic area until conditions are conducive to their return. Mobile epibenthic organisms similarly will leave the area if possible. Planktonic communities that are unable to swim away from a hypoxic water mass, or benthic communities associated with specific water bottoms, would be subject to stress and/or mortality depending on the severity of the hypoxic event and their length of exposure to it.

Observed Impacts

The distribution of fishery species is affected by displacement of demersal nekton and mobile epibenthic species assemblages and communities to areas with sufficient dissolved oxygen, and disruption of species movement patterns. Numbers of demersal species, and their abundance, are reduced greatly (Bedinger, et al., 1980; Stuntz, et al., 1983). Pihl, et al. (1991) found that demersal species tended to migrate to shallower water to escape hypoxic bottom conditions.

Preliminary indications are that pelagic species have not been impacted, although severe hypoxic conditions extending high into the water column may affect their distribution and movement patterns. Stuntz, et al. (1983) speculated that pelagic species may congregate around hypoxic water bottoms to take advantage of feeding opportunities on benthic, epibenthic, and demersal organisms that are rendered vulnerable to predation by stress resulting from low oxygen levels. Pihl, et al. (1992) observed a similar phenomenon in demersal species in Chesapeake Bay.

Otter trawls of the type used in the LDWF surveys are designed to collect organisms that reside on or near the bottom. Therefore the catch from this gear generally is comprised of epibenthic and demersal species. Reef-associated species sometimes are caught if the gear passes over an irregularly-contoured area of the bottom that provides reef-like habitat, or if the animals are moving between reef areas. Pelagic species can be caught near the bottom if a school is encountered as the gear is fishing, or off-bottom as the gear is being set or retrieved. The plankton net data reported here were collected in a survey to determine zooplankton species composition and abundance in near-bottom offshore waters subject to hypoxic conditions. Seventy-five species of finfishes, crustaceans, and cephalopods were collected in the Department's fishery-independent trawl surveys in the area where hypoxic conditions occur. The LDWF data indicate that a variety of epibenthic, demersal, pelagic, and reef species were present in both trawl and plankton net catch from the hypoxic zone (Table 4). Target species for directed fisheries, both commercial and recreational, were recorded in the catch regularly.

Composition and abundance of species caught in trawls decreased with D.O. concentration. The LDWF data indicate that 35 percent of nearshore trawl samples collected from hypoxic waters during summer result in no live organisms being caught. Large catches from hypoxic or anoxic waters generally were comprised of pelagic species. Trawl catch in waters with D.O. concentrations between 0.0 and 1.0 mg/l was comprised of 34 species (Figure 59). Although the number of taxa encountered was only slightly less than that found at D.O. concentrations above 3.0 mg/l, the total number of individuals was significantly depressed. Between 1.0 and 2.0 mg/l of D.O., the number of species caught decreased to 24, but the number of individuals in the catch increased by nearly an order of magnitude. Between 2.0 and 3.0 mg/l of D.O. the number of species increased to 46 while the number of individuals decreased slightly. The number of species remained relatively constant as D.O. concentrations rose from 3.0 to 4.0 mg/l, and the number of individuals increased by approximately 33 percent. Weight of the catch exhibited a nearly linear increase as D.O. concentrations rose (Figure 60). Pelagic species exhibited a nearly constant relative abundance in trawl catches, remaining approximately at 20 percent except at D.O. concentrations between 2.0 and 3.0 mg/l (Figure 61). Of the 34 species found between D.O. concentrations of 0.0 and 1.0 mg/l, approximately one-third were epibenthic species that may not have been able to avoid the development of hypoxic conditions. The increase in numbers of individuals between 1.0 and 2.0 mg/l D.O. suggests that animals may be congregating around the margins of the hypoxic area, upon being displaced as the event develops. The relative abundance of pelagic species increased when D.O. concentrations increased between 2.0 and 3.0 mg/l. This increase may be due not only to availability of prey organisms under stress from low D.O. concentrations, but also to increased numbers of prey that have been concentrated by hypoxia.

Potential Impacts

The observed impacts to fisheries vary with the decrease in D.O. concentration, and presumably with the area of the water bottoms that are affected by hypoxic conditions. Mobile organisms move from hypoxic waters to congregate in areas where D.O. concentrations are sufficient to sustain life. Animals unable to move away from developing hypoxic/anoxic waters, either because of life stage or habit, are subject to mortality. The observed redistribution of species, concentration of abundance, and mortality that hypoxic conditions cause may also contribute to other potential impacts to Gulf of Mexico fisheries.

Numbers of pelagic species appear to increase in response to availability of prey organisms concentrated at the edges of the hypoxic area. Numbers of fishermen may increase in these areas for similar reasons. The concentration of fishing effort may result in increased harvest of target and non-target species. If the relative abundance of nontarget species is high in these areas, increased bycatch mortality may result. Similarly, localized overfishing in some areas may be possible if the relative abundance of target species is high. Additionally, if the fishery is prosecuted over a limited area, much of which is affected by hypoxic bottom water, the relatively high proportion of target species can lead to local overharvest.

Particularly severe hypoxic events, or those that impinge closely upon the shoreline, may leave no escape for organisms displaced and crowded by low D.O. concentrations. As a result, localized mortality of finfish and shellfish in shoreline areas may occur. Hypoxia was a factor in a 1973 jubilee and fish kill at Grand Isle (Philip E. Bowman, LDWF, personal communication). Further impingement on the shoreline and encroachment into bay waters may impact the oyster fishery. Adult oysters will shut their valves to withstand hypoxic conditions for short periods of time. If hypoxic conditions persist for days, however, mortality is likely. Furthermore the peaks of oyster spawning are in early and late summer, when hypoxic conditions may exist. Larval oysters, as well as the eggs and larvae of other fishery species, are components of zooplankton assemblages and therefore potentially are subject to stress and/or mortality from exposure to hypoxic conditions (Earl Melancon, Nichols State University, Thibodaux, Louisiana, personal communication). Decreased recruitment to fishery stocks, disease, or slow growth due to exposure to hypoxia are other potential impacts to zooplankton species assemblages. Changes in the relative amounts of nutrients may affect phytoplankton community dynamics, resulting in changes throughout the food web; replacement of diatoms with cyanobacteria or dinoflagellates may result in development of red and brown tides with resultant adverse impacts to fisheries.

Low catch rates have been demonstrated in research and resource surveys (Pavela, et al., 1983; Bedinger, et al., 1980). Similar decreases in directed fisheries have been reported (Krapf, 1994; Barton, 1995). Changes in the distribution and abundance of fishery species may result in a loss of commercial and recreational harvest opportunities and a net economic loss to the State. Fishermen may have to travel farther to productive waters until the point where the economic outlay does not equal the expected return. The recreational fisherman's response may be to reduce fishing effort, and therefore, fishing-related expenditures. Decreased catch in the commercial fishery may affect a suite of related industries, including processors, wholesalers, retailers and restaurants, resulting ultimately in a loss in economic activity. Economically marginal commercial participants may leave the fishery. Hypoxia was cited as one of the factors that led to the closing of the Zapata menhaden processing plant in Dulac, Louisiana in 1995 (Barton,1995).

Fishery-independent data provide indices of population levels to fishery managers. In a highly regulated fishery these data provide the only available measure of changes in population levels. The changes in distribution of species resulting from hypoxia, movement away and concentration, may result in more resource survey samples with high and low abundance. This will result in an increase in the sample variances of resource survey data. Population estimates based on these data will be less precise. Fishery managers then must allow for the larger confidence interval surrounding population estimates in formulating management decisions regarding seasons and quotas.

Summary

Louisiana's fisheries, and to a large extent those of the northern Gulf of Mexico, depend on the Mississippi River for their existence. The sediments and nutrients carried by the river built the Louisiana coastal marshes. Today, as a result of leveeing the river, nutrients and sediments that once built and maintained Louisiana's coastal marshes are being deposited off the Continental Shelf in the abyssal depths of the Gulf of Mexico. Decreasing the nutrient levels in the Mississippi River may serve to lessen the severity of hypoxia in coastal waters, but also may impact the food web of the northern Gulf and decrease fisheries production.

Distributional changes that can be related to hypoxia have been observed in demersal fish and invertebrate communities. Plankton communities are subject to stress and mortality in hypoxic waters since these organisms lack the ability to avoid the area. Preliminary indications are that pelagic species have not yet been affected, other than a possible change in local population density related to feeding behavior. However, an increase in the severity of the phenomenon that leads to hypoxic waters extending high into the water column potentially can also impact the distribution and movement of these highly-mobile species.

Other potential impacts include a concentrating of fishing effort resulting in increased harvest; low catch rates in directed fisheries; localized overfishing; mortality; decreased recruitment due to impacts to zooplankton. Changes in the concentrations of nutrients, such as silicate, can result in a change in phytoplankton community dynamics, and subsequent changes throughout the food web. Diatoms replaced by dinoflagellates may result in development of red and brown tides with resultant adverse impacts to fisheries, such as advisories against catching/keeping certain species, off-flavors, and direct mortality. Changes in the distribution and abundance of fish species could result in a loss of commercial and recreational harvest opportunities and a net economic loss to the State. Economically marginal commercial participants may leave the fishery, and recreational participants may reduce fishing effort. Fishery management decisions that are based on fishery-independent data from resource surveys that do not take hypoxia into account may result in a loss of precision in assessment of fishery stocks.

References

Barton, E.A. 1995. Dead zone blamed for plant's closure. Houma Daily Courier. November 6, 1995.

Barrett, B.B., J.W. Tarver, W.R. Latapie, J.F. Pollard, W.R. Mock, G.B. Adkins, W.J. Gaidry, C.J. White, and J.S. Mathis. 1971. Cooperative Gulf of Mexico estuarine inventory and study, Louisiana. Phase II, Hydrology and Phase III, Sedimentology. Louisiana Wildlife and Fisheries Commission. New Orleans, Louisiana. 191 pp.

Bedinger, C.A., J.W. Cooper, A. Kwok, R.E. Childers, and K.T. Kimball. 1980. Ecological investigations of petroleum production platforms in the central Gulf of Mexico. Volume 1: pollutant fate and effects studies. Draft final report submitted to the Bureau of Land Management, Contract No. AA551-CT8-17. 149pp.

Dortch, Q. 1994. Changes in phytoplankton numbers and species composition. pp. 4649. in. Dowgiallo, M.J., Editor. Coastal oceanographic effects of summer 1993 Mississippi River flooding. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Faganeli, J., A. Avcin, N. Fanuko, A. Malej, V. Turk, P. Tusnik, B. Vriser, and A. Vukovic. 1985. Bottom layer anoxia in the central part of the Gulf of Trieste in the late summer of 1983. Marine Pollution Bulletin. 16(2):75-78.

Foote, K.J. 1982. Observations of oxygen depletion during LOOP environmental studies. (Abstract). Presented at: Gulf of Mexico Information Transfer Meeting. U.S. Department of the Interior, Minerals Management Service. August 24-26, 1982.

Harper, D.E., Jr, L.D. McKinney, R.R. Salzer, and R.J. Case. 1981. The occurrence of hypoxic bottom water off the upper Texas coast and its effects on the benthic biota. Contributions in Marine Science 24:53–79.

Harris, A., J. Ragan, and J. Green. 1978. The recurrence of oxygen-deficient waters in a shallow marine environment. (Abstract). In. American Association for the Advancement of Science. Abstracts of papers of the 144th national meeting.

Holstrom, D. 1993. Mississippi flooding leaves a toxic legacy: pollution in the Gulf of Mexico. Christian Science Monitor. September 7, 1993.

Krapf, D. 1994. Gulf shrimp. National Fisherman. April, 1994.

Pavela, J.S., J.L. Ross, and M.E. Chittenden. 1983. Sharp reductions in abundance of fishes and benthic macroinvertebrates in the Gulf of Mexico off Texas associated with hypoxia. Northeast Gulf Science 6(2):167–173.

Perret, W.S., B.B. Barrett, W.R. Latapie, J.F. Pollard, W.R. Mock, G.B. Adkins, W.J. Gaidry, and C.J. White. 1971. Cooperative

Gulf of Mexico estuarine inventory and study, Louisiana. Phase 1, Area description and Phase IV, Biology. Louisiana Wildlife and Fisheries Commission. New Orleans, Louisiana. 174pp.

Pihl, L., S.P. Baden, and R.J. Diaz. 1991. Effects of periodic hypoxia on distribution of demersal fish and crustaceans. Marine Biology. 108:349-360.

Pihl, L., S.P. Baden, R.J. Diaz, and L.C. Schaffner. 1992. Hypoxia induced structural changes in the diet of bottom-feeding fish and crustacea. Marine Biology. 112:344361 .

Rabalais, N.N., R.E. Turner, W.J. Wiseman, Jr., and D.F. Boesch. 1985. Hydrographic, biological, and nutrient characteristics of the water column on the Louisiana shelf, July and September,1985. Louisiana Universities Marine Consortium. Data Report Number 3.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman, Jr. 1994. Hypoxic conditions in bottom waters on the Louisiana-Texas shelf. pp. 50–54. in. Dowgiallo, M.J., Editor. Coastal oceanographic effects of summer 1993 Mississippi River flooding. U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Ragan, J.G., A.H. Harris, and J.H. Green. 1978. Temperature, salinity, and oxygen measurements of surface and bottom waters on the continental shelf off Louisiana during portions of 1975 and 1976. Professional Papers Series (Biology), Number 3. Nichols State University, Thibodaux. Louisiana.

Renaud, M.L. 1986. Hypoxia in Louisiana coastal waters during 1983: implications for fisheries. Fishery Bulletin 84(1):19–26.

Richards, F.A. 1957. Oxygen in the ocean. pp 185–238 in: Hedgepeth, J.W., ed. Treatise on marine ecology and paleoecology. Geological Society of America. Memoir Number 67. Volume 1.

Schurtz, M.H., and K.M. St. Pe'. 1984. Water quality investigation of environmental conditions in Lake Pontchartrain, report on interim findings. Louisiana Department of Environmental Quality, Water Pollution Control Division. 85pp. Appendix.

Stuntz, W.E., N. Sanders, T.D. Leming, K.N. Baxter, and R.M. Barazotto. 1983. Area of hypoxic bottom water found in northern Gulf of Mexico. Coastal Oceanography and Climatology News. 4:37-38.

Turner, R.E., and R.L. Allen. 1982a. Bottom water oxygen concentration in the Mississippi River Delta Bight. Contributions in Marine Science. 25:161-172.

Turner, R.E., and R.L. Allen. 1982b. Plankton respiration rates in the bottom waters of the Mississippi River Delta Bight. Contributions in Marine Science. 25:173-179.

Table 4.
Summary of species caught in LDWF trawl and plankton net samples from nearshore waters, 1978–1995. Bold type indicates a species sought either in the commercial or recreational fishery.

Species Type	Species
Epibenthic	Mud creabs, purse crabs, spider crabs, other crabs, batfish, **southern flounder, ocellated flounder**, other flounders, soles
Demersal	**White shrimp, brown shrimp, blue crab**, mantis shrimp, other swimming crabs, sharpnose shark, anchovies, lizardfishes, catfishes, cusk-eels, **spotted seatrout, sand seatrout, silver seatrout, southern kingfish, croaker**, other drums, sea basses, searobins, puffers
Pelagic	**Squids, Gulf menhaden, other herrings,** spadefish, **Spanish mackerel**, Atlantic bumper, other jacks, bluefish, Gulf butterfish, harvestfish
Other species	Berracudas, pinfish, **red snapper,** mojarras, seahorses, filefish, **triggerfish,** remoras
Plankton	**Brown shrimp, seabob**, other shrimp, **blue crab,** other swimming crabs, anchovies, **herrings,** jacks, **sand seatrout, spotted seatrout, red drum,** other drums, **Spanish mackerel**, other species

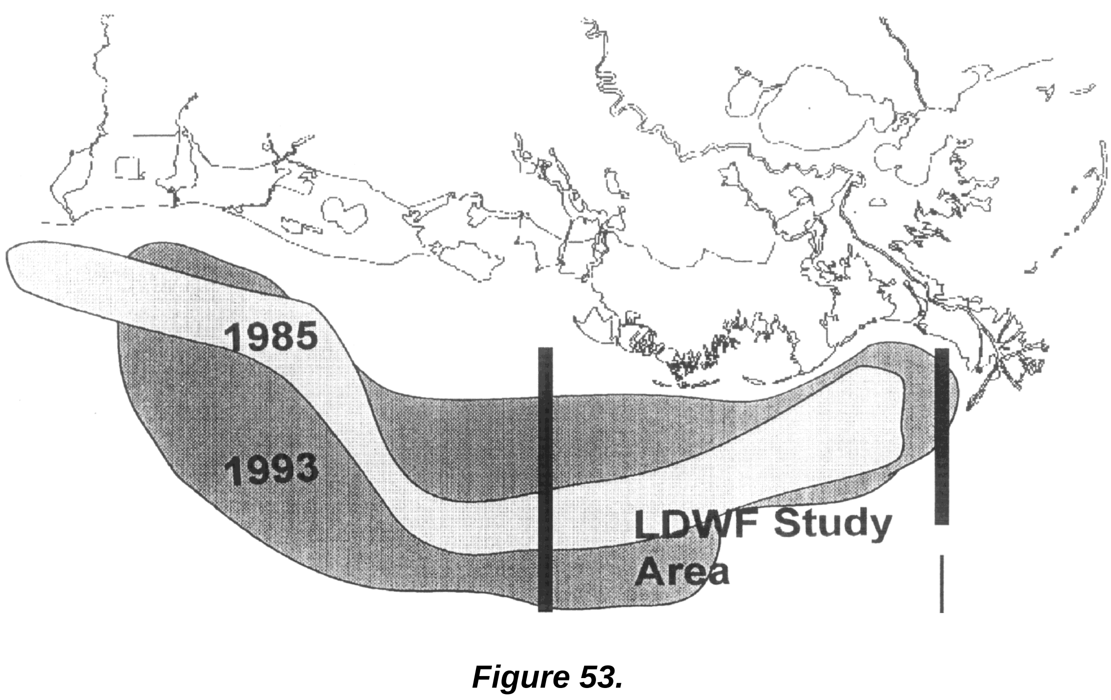

Figure 53.
Map of coastal Louisiana showing approximate side and location of 1985 and 1993 hypocix events, and the location of the LDWF study area.

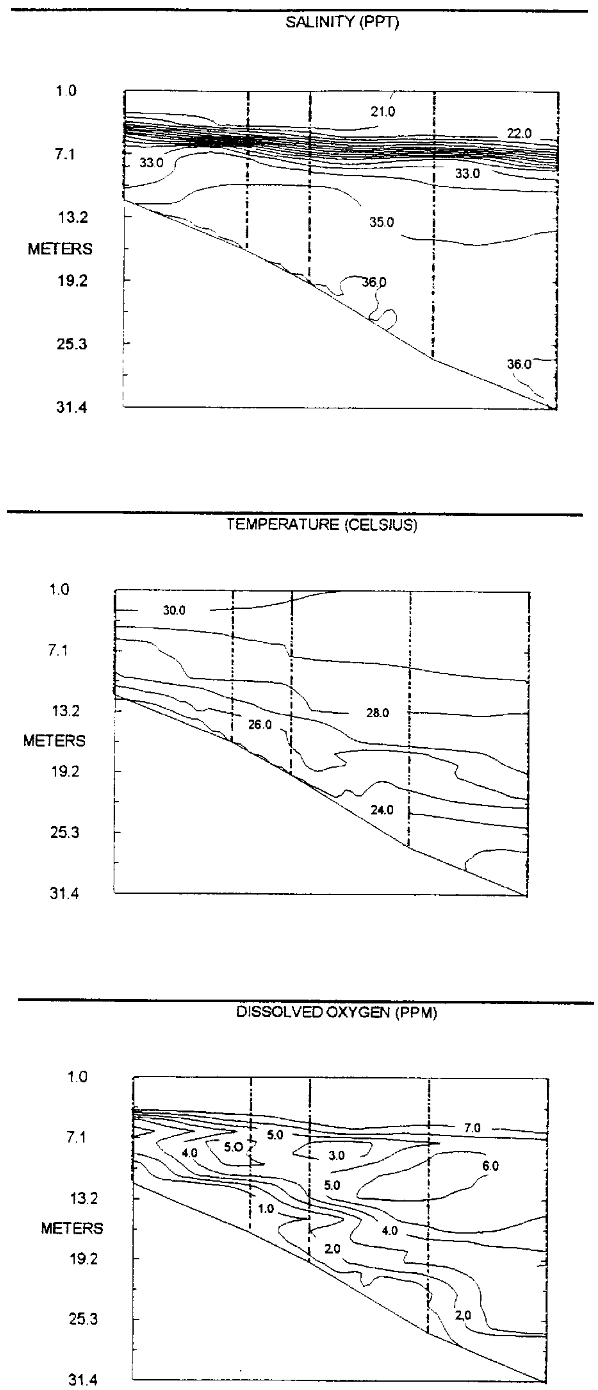

Figure 54.

Nearshore water column profile showing stratification based on salinity (top) and depression of dissolved oxygen concentration in near-bottom waters (bottom). LDWF data, July 1995, sample.

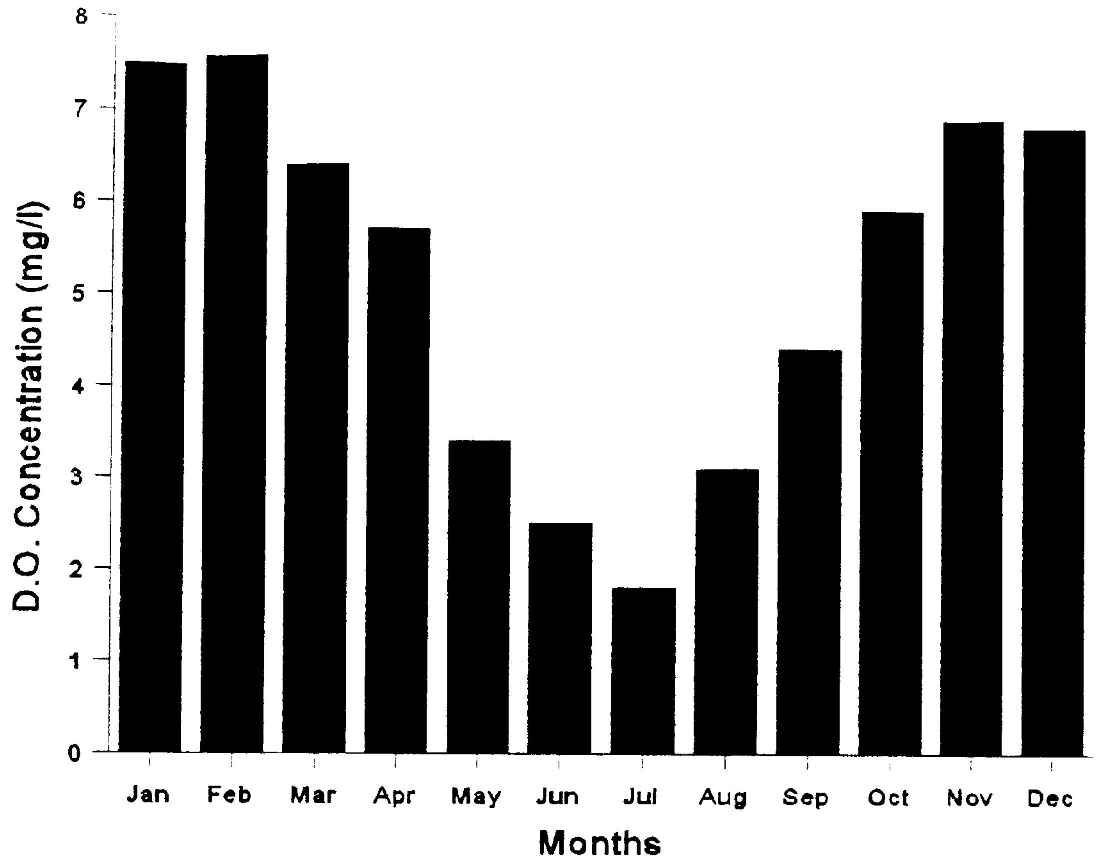

Figure 55.
Monthly mean concentration of dissolved oxygen in bottom waters at nearshore LDWF stations, 1978–1995.

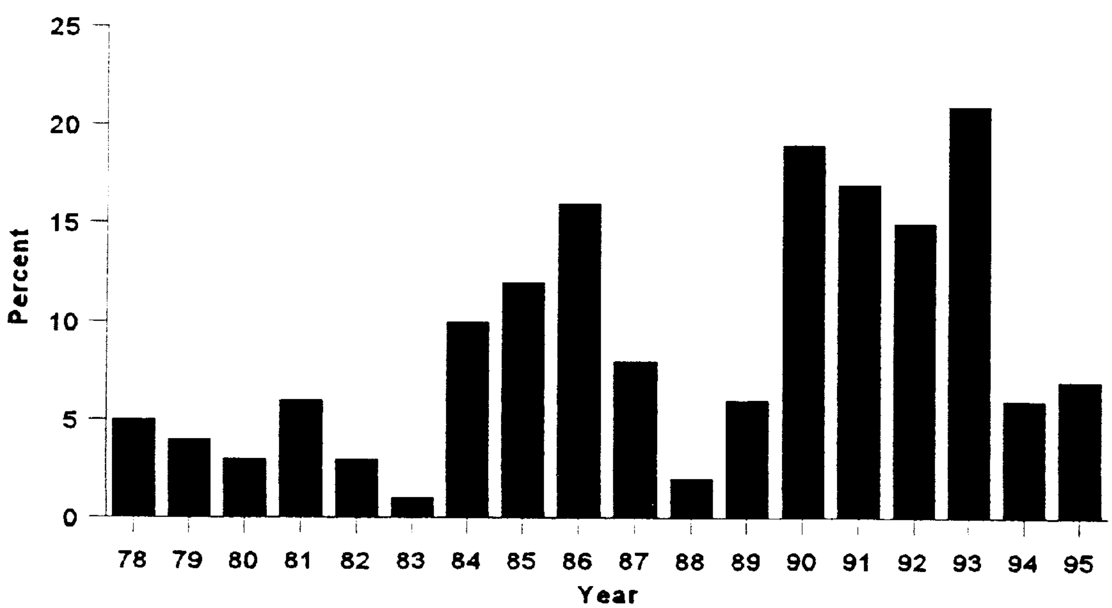

Figure 56.
Percent occurrence of hypoxic conditions in bottom waters at nearshore LDWF stations, 1978–1995.

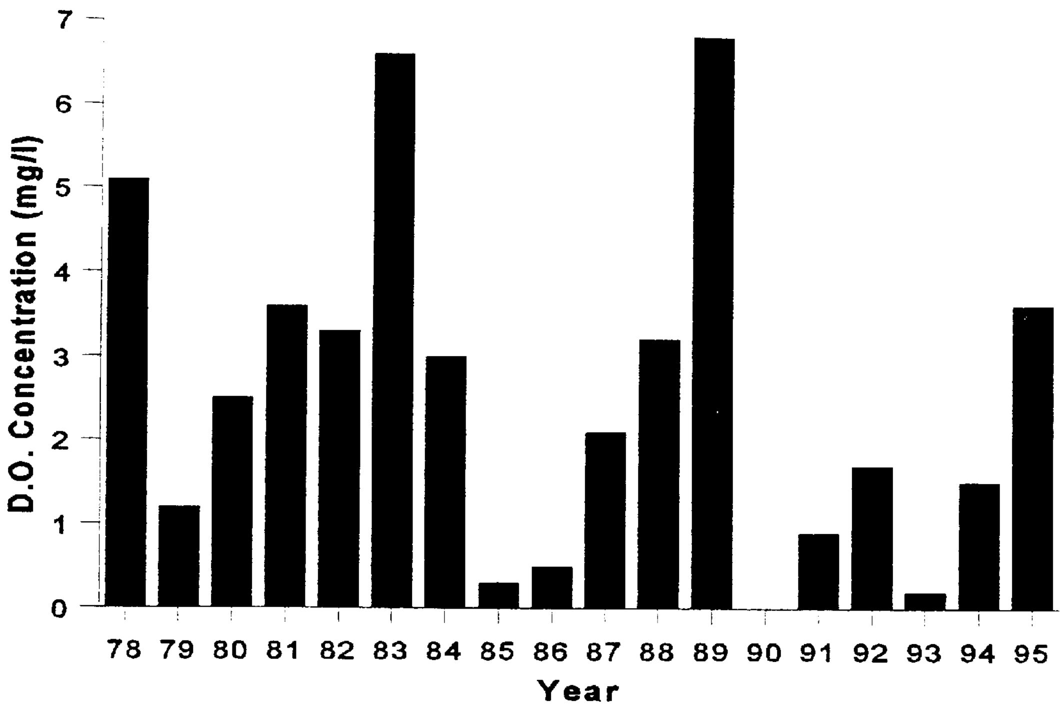

Figure 57.
Mean summer (June, July, and August) dissolved oxygen concentration in bottom waters at nearshore LDWF stations, 1978–1995.

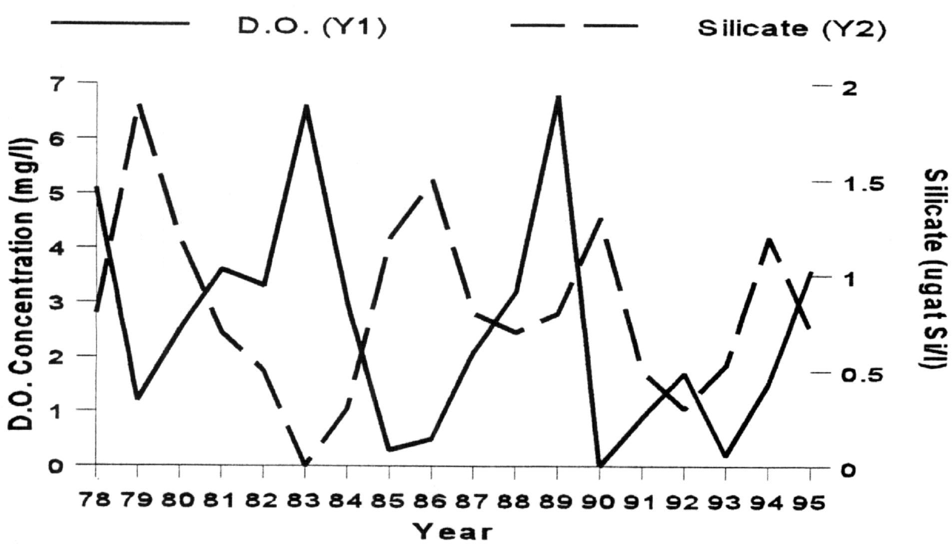

Figure 58.
Concentrations of silicates in surface waters during spring months (April, May, and June) and summer (June, and August) dissolved oxygen concentration in bottom waters from LDWF nearshore stations, 1978–1995.

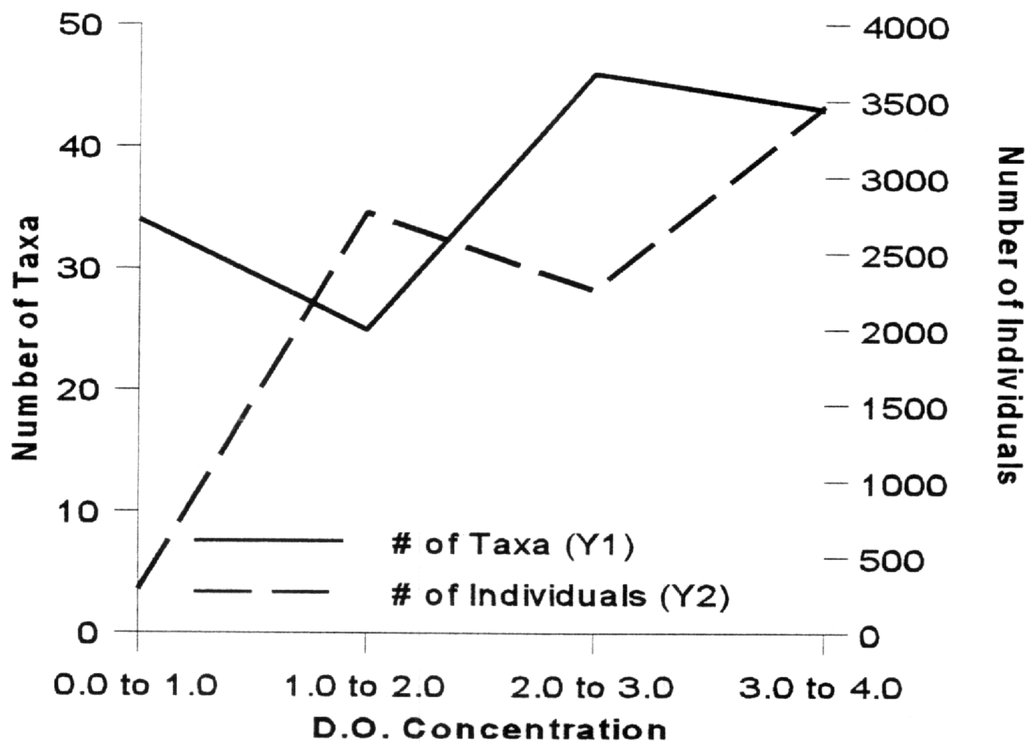

Figure 59.
Numbers of taxa and total numbers of individual organisms caught in LDWF trawl samples from nearshore waters, 1978–1995.

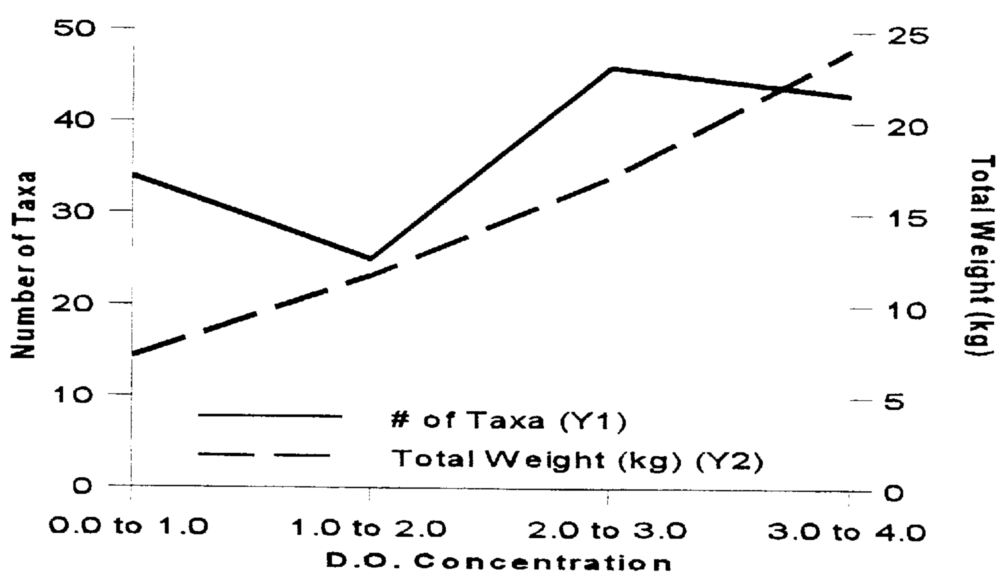

Figure 60.
Numbers of taxa and total weight of catch from LDWF trawl samples a at nearshore stations, 1978–1995.

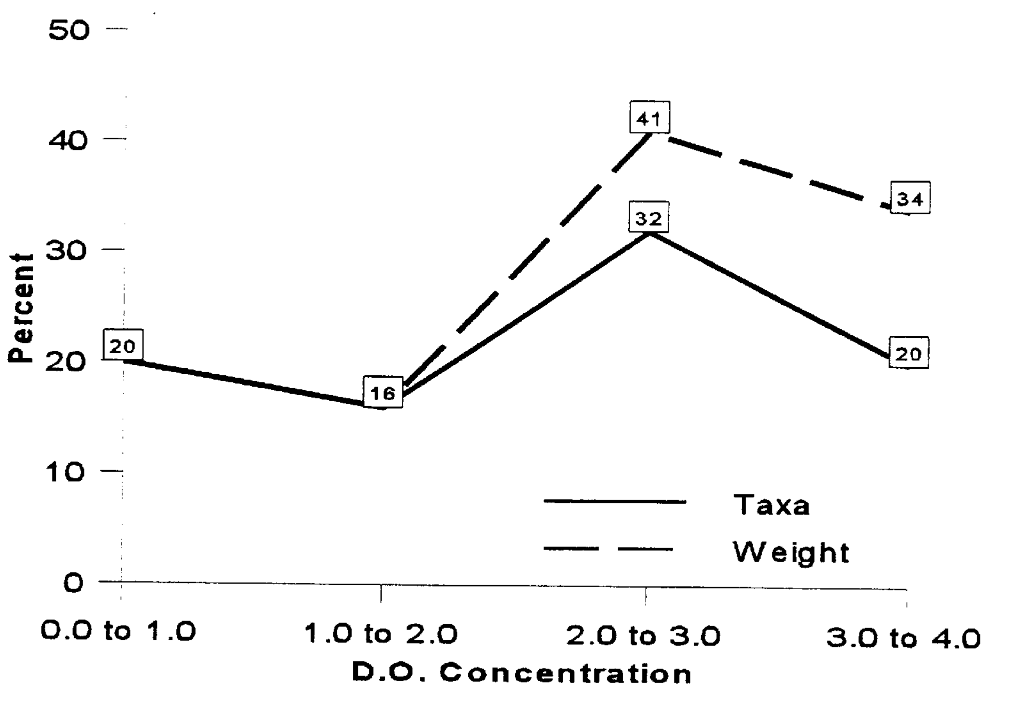

Figure 61.
Numbers of taxa and total weight of catch from LDWF trawl samples at nearshore stations, 1978–1995.

Presentation Discussion

Jim Hanifen (Louisiana Department of Wildlife & Fisheries)

Eugene Turner *(Louisiana State University— Baton Rouge, LA)* commented that the silicate and low dissolved oxygen relationship illustrates many of the problems encountered during large data set investigations. He believed there could be a surrogate which is represented by the silicate relationship demonstrated by a lag between the silicate and dissolved oxygen which have been shown by several models and analyses to be similar with the loadings in the river and hypoxia offshore. The silicate may be a surrogate for salinity or loading because the lower the salinity the higher the silicate. The silicate concentration has been relatively steady through the study year compared with previous years. However, that may be a result of stratification. The same relationship may be demonstrated if salinity were plotted against dissolved oxygen. Therefore, these types of studies should be conducted for more than one year. Unfortunately, funding for ten year studies is rarely available.